
Image processing for enhanced observer agreement in the evaluation of periapical bone changes

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Abstract

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Aim The aim of the present study was to evaluate the effect of root canal treatment on periapical lesions by conventional and subtracted digital radiographic images of clinical cases.

Methodology Eleven patients who exhibited clinical or radiological signs of periapical pathology received root canal treatment. Periapical radiographs were obtained immediately postoperatively and recall radiographs at intervals of 3, 6, 9 and 12 months postoperatively were obtained. Identical exposure geometry was maintained. From the standardized radiographs digitized images were produced. Four experienced practitioners interpreted the radiographs and the digitized images. They assessed 59 pairs of images projected at random using a slide projector. On the left side, there was a reference image with no lesion, and on the right an image either with or without a

lesion. Each reader was asked to rate each pair of images on a three-point scale: yes, absolutely sure that gain or loss was present; uncertain, if there was gain or loss; no, absolutely sure that no gain or loss was present. There was no time limit for each decision. Inter- and intra-examiner agreement was analyzed using the kappa-statistic for the diagnosis of periapical bone density changes in the periapical region at the different time points either in conventional pairs of radiographs or using digital subtraction images.

Results The inter-examiner agreement ($P \leq 0.001$) and the intra-examiner agreement ($P = 0.02$) when digital pictures were evaluated were significantly higher than with conventional radiographs.

Conclusions A highly significantly better observer agreement was achieved by digital subtraction radiography during the evaluation of the outcome of root canal treatment on periapical lesions.

Keywords: dental radiology, periapical disease, subtraction radiography.

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Introduction

The value of conventional radiographic techniques in the evaluation of periapical lesions is limited. Bender & Seltzer (1961a,b) and Wengraf (1964) showed that the lesions artificially created in human dry mandibles and maxillas could not be detected radiographically if they

were limited to cancellous bone. Ramadan & Mitchell (1962) reported a similar finding and also noted that the removal of the entire buccal or lingual plate did not affect the radiographic architectural pattern of bone. In addition, localized defects superimposed by roots were not seen in most cases. Regan & Mitchell (1963) found 18 periapical radiolucencies in 289 teeth of 57 human cadavers. Lesions were apparent radiographically if the cortical plate was perforated or thinned. Pauls & Trott (1966) reported that defects created in cancellous bone with dental burs could not be detected unless the

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cortical plate was perforated or extensive destruction of the cortex from the outer or inner surface was present. Even perforation through root sockets into the maxillary sinus in dry skulls was not visible on radiographs (Schwartz & Foster 1971).

The size of radiographically observed lesions did not correlate with actual tissue destruction (Bender & Seltzer 1961a,b). In general, lesions analyzed clinically or histologically were found to be much larger than when estimated radiographically (Bender *et al.* 1966, Shoha *et al.* 1974). Shoha *et al.* (1974) were able to show artificially created lesions involving only cancellous bone in radiographs of the premolar region in dry skull specimens. From 68 lesions limited to cancellous bone, LeQuire *et al.* (1977) could detect 57 radiographically. Bender (1982) tested the percentage of mineral bone loss, i.e. required to produce a radiolucent area in dry skulls. It was estimated that a mineralized bone loss of greater than 7% in cortical bone was necessary considering soft tissue X-ray absorption and consistency in radiographic visualization. A value for cancellous bone could not be determined.

The interpretation of periapical structures in dental radiographs is subjective. In the study of Goldman *et al.* (1972), the same 253 cases that had been examined by six independent examiners previously were re-examined 6–8 months later by three of the original examiners. Each examiner's results were then compared with his original results. They agreed with themselves between 72 and 88% of the time in various categories. The analysis, however, showed large discrepancies in almost all categories of comparisons. Gelfand *et al.* (1983) reported an intra-examiner disagreement of 21.8%, using 10 cases of the material in Goldman's study. Only in 50% of the evaluated cases was the inter-examiner agreement greater than 50%. In the study of Duinkerke *et al.* (1975), the intra-examiner discrepancy in tracing periapical lesions varied between 21 and 37%; the inter-examiner difference was 14–52%. Zakariasen *et al.* (1984) reported that intraobserver agreement was between 64.5 and 81% and that inter-examiner agreement was only 38%. Using more information by analysing three radiographs taken at different angles, the intraobserver agreement rose from 70 to 87% (Brynnolf 1970).

In order to make endodontic diagnosis more reliable and to detect subtle changes in the mineral content of periapical areas, alternative methods have been tested for their ability to improve lesion detection. A comparison between xeroradiography (Gratt *et al.* 1986) and conventional radiographs showed high similarity in

the interpretation of periapical areas. Large observer variation with both methods has been reported (Petersson *et al.* 1984). The interpretation of a normal periapical bone region seemed to be facilitated with xeroradiography, probably because this technique has the advantage of edge enhancement (Gratt *et al.* 1986). Artefacts may however, interfere with areas of diagnostic interest.

Densitometric analysis distinguished reproducibly areas where bone was removed in dry mandibles, whereas the conventional interpretation of the same material by 10 dentists varied considerably (Duinkerke *et al.* 1977). Interfacing a computer with a densitometer allows the analysis of more scans covering whole films. Such precursors to modern image analysers were described by Ando *et al.* (1969) in connection with periapical imaging. The density was scanned at 5400–5600 sampling points. These values were converted to a number between 0 and 255 and then displayed into two different colour levels.

Klein (1967) reported an electronic subtraction technique. Using two film cameras viewing two radiographs, one image could be subtracted electronically from the other. Kassle & Klein (1976) compared television subtraction with viewing box examination of conventional films. The subtraction readout enhanced the diagnostic image. Periapical changes, induced in 45 mandibular molar and premolars of seven Beagle dogs, were identified 7–42 days before they were seen using conventional techniques.

There is currently little literature on any application of digital subtraction radiography to periapical bone changes. Digital subtraction techniques have so far been reported for the diagnosis of periodontal lesions changes *in vitro* (Kullendorff *et al.* 1988) and in animal models (Pascon *et al.* 1987). Kullendorff *et al.* (1988) evaluated the diagnostic potential of subtraction and conventional radiography to assess periapical bone lesions. The periapical region of dry human mandibles was radiographically examined, subjectively evaluated and measured by ¹²⁵I absorptiometry before and after the creation of bone defects. There was a higher diagnostic accuracy using the subtraction technique. For a lesion depth corresponding to <2 mm of compact bone, there was a clear difference between the techniques, but for deeper lesions the conventional technique gained force. The subtraction technique was significantly superior for lesion confined to cancellous bone. The statistical difference in the diagnostic utility of subtraction compared with conventional technique was found to be less for lesions of the cortical bone. Therefore, they concluded that

subtraction radiography improves the detection of small lesions in the periapical bone area. Pascon *et al.* (1987) used teeth of two baboons to establish a methodology for the development of predictable periapical lesions. Radiographic analysis by subtraction radiography showed hard tissue changes as early as 7 days. The method predictably developed periapical lesions, which could be monitored by subtraction radiography, and there was a correlation established between radiographic and histologic findings.

The aim of the present study was to assess changes within periapical lesions after root canal treatment by conventional and subtracted digital images in clinical situations.

Materials and methods

Original radiographic material

Eleven patients (21–65 years of age) who exhibited clinical and radiological signs of periapical pathology were selected. The selected teeth had periapical lesions not larger than 6 mm in diameter as seen on the periapical radiographs following root canal treatment. Standardized periapical radiographs were obtained immediately postoperatively and at 3, 6, 9 and 12 months; at the same times a complete clinical endodontic examination and clinical periapical diagnosis were performed. At each stage standardized periapical radiographs were obtained using individualized acrylic bite blocks and a modification of the Rinn system. Kodak Ekta speed film (Eastman Kodak Company, Rochester, NY, USA) was used. Radiographic exposures were made using a dental X-ray unit (X-Mind de Gotgen, Milan, Italy) operating at 70 kVp, 8 mA and 0.40 s exposure time. The focus to object distance was 45 cm. All exposure conditions, film processing and evaluation procedures were identical. The 12-month radiographs were used to determine whether healing was present or not and these radiographs were considered as the gold standard. None of the patients had uncontrolled systemic disease, patients who needed antibiotic cover for endodontic therapy and pregnant patients were excluded.

Acquisition of the digital subtraction images

To fulfil one of the basic requirements for subtraction radiography, standardized pairs of images of the same object were taken with identical geometry and image processing procedures. The Rinn system (Updegrave

1951) was modified by attaching the film-holder-device rigidly to the tubes. Biting in an acrylic index (Coe Tray Plastic) fixed to the film holder device the patient was able to bite into the correct repeatable position. These modifications provided acceptable superimposable images for digital subtraction radiography. Other factors influencing the film density were kept constant.

Digital subtraction images

From a pair of standardized radiographs to be compared densitometrically, digitized pictures were taken using a commercial black-and white CCD camera (Hitachi Ci-20 p.m., Tokyo, Japan; 734×580 pixels, specially adapted for picture processing) and a frame grabber hardware card (Matrox MVP/AT, Matrox Electronic Systems Ltd, Quebec, Canada H9P 2T4) in a microcomputer (Compaq 386/20, Compaq Computer Co., Houston, TX, USA, with VGA Graphics, 60 MB Hard drive and 4 Mega Extend RAM). The image-processing system allowed the capture of four frames on board with a resolution of $512 \times 512 \times 8$ pixels.

Before evaluating radiographic density differences between the two standardized radiographs, each follow-up radiograph was aligned to the stored baseline image. This superimposition took place in three steps. To obtain a first alignment, the baseline image was divided into a chessboard format. The follow-up radiograph was then shifted and rotated until the two images were superimposed, showing 50% of the image on the monitor originating from the stored baseline image and the corresponding 50% from the follow-up radiograph. Changing the display from the baseline to the follow-up image in a flickering manner, a second adjustment was performed until the two images were perceived as one stable image on the monitor. For the third adjustment, the real-time subtraction image was displayed on the video monitor, which allowed exact adaptation of the two images. After the best possible superimposition had been achieved using the micrometer screws for axial and rotational alignment, the follow-up image was finally grabbed, and a coarse intensity adjustment was performed using the frame grabbers electronic gain and offset adjustment.

The superimposition was based on the assumption that the film planes did not change between two exposures for a pair of standardized radiographs. In addition, this method did not compensate for projection errors caused by film bending, but the real-time subtraction allowed for an optimal alignment over the area of interest.

To correct for changes in density caused by different exposure and/or developing conditions, the gray level histograms of the two images were compared and adjusted using a non-parametric contrast correction method. After the gray level adaptation, a subtraction image from a site where absolutely no change in density had occurred showed a perfect cancellation of the structures. An average gray level value of 128 (the middle of the digitizer gray level range set by software) showed up at each pixel. Areas with gray levels less than 128 in the subtraction image (appearing dark against the background of 128) indicated loss in density and areas with gray levels greater than 128 (appearing bright against the background of 128) indicated and increase in density.

Contrast-enhanced digital subtraction images

The original digital subtraction image could theoretically demonstrate gray levels between 0 and 255. Because this method was, however, used to depict small changes in density over time, most of the pixels were expected to demonstrate a gray level near 128 (in the range between 100 and 156). Therefore, the lookup table was modified interactively with an adjustable ramp stretching an individually chosen range of gray levels in the image.

Colour-coded digital subtraction images

The lookup table could also be changed to display any given intensity in the subtraction image to different colours. The following colour composition was chosen: gray levels between 115 and 0 were depicted in ascending intensities of red; gray levels between 115 and 141 were displayed in one intensity of green; gray levels between 141 and 255 were depicted in descending intensities of blue.

The colour conversion resulted in subtraction images in which the range of gray levels between 115 and 141 appeared green (representing no change in bone density), gray levels from 0 to 115 appeared red (representing loss in density), and gray levels from 141 to 255 appeared blue (representing increase in density).

Regions of interest colour-coded image

Regions of interest in the subtracted colour-coded image to be interpreted were outlined and projected on top of the originally digitized black and white radiograph for better localization of the structures of interest.

Interpretation of the images

Four practitioners interpreted the sets of radiographs. They assessed 59 pairs of images projected at random using a slide projector. On the left side, there was a reference image with no lesion, and on the right an image with or without a lesion. Each reader was asked to rate each pair of images on a three-point scale: yes, absolutely sure that gain or loss was present; uncertain, if there was gain or loss; no, absolutely sure that no gain or loss is present. There was no time limit for each decision.

Data analysis

For the diagnosis of periapical bone density changes at different time points either in conventional pairs of radiographs or using digital subtraction images inter- and intra-examiners agreement was analyzed using the kappa-statistic.

Results

Examples of the images obtained are shown in Figs 1 and 2.

Inter-examiner agreement

Figure 3 shows the results of the inter-examiner agreement. The agreement between the examiners when digital radiographic images were evaluated was statistically significantly higher compared with conventional radiographs (kappa value for digital radiographic images 0.89 ± 0.05 ; for conventional radiographs 0.25 ± 0.03 ; $P \leq 0.001$ by Mann-Whitney *U*-test).

Intra-examiner agreement

Figure 3 right shows the intra-examiner agreement. Digital interpretation showed statistically significantly better results than conventional radiographs (kappa value for digital radiographic images 0.83 ± 0.13 ; for conventional radiographs 0.32 ± 0.11 ; $P = 0.02$ by Mann-Whitney *U*-test).

Discussion

The large variation noted amongst clinical and radiographic studies on the outcome of root canal treatment could partly be explained by difficulties in defining and maintaining criteria for radiological evidence of periapical diseases (Reit & Hollender 1983). Clinical evaluation

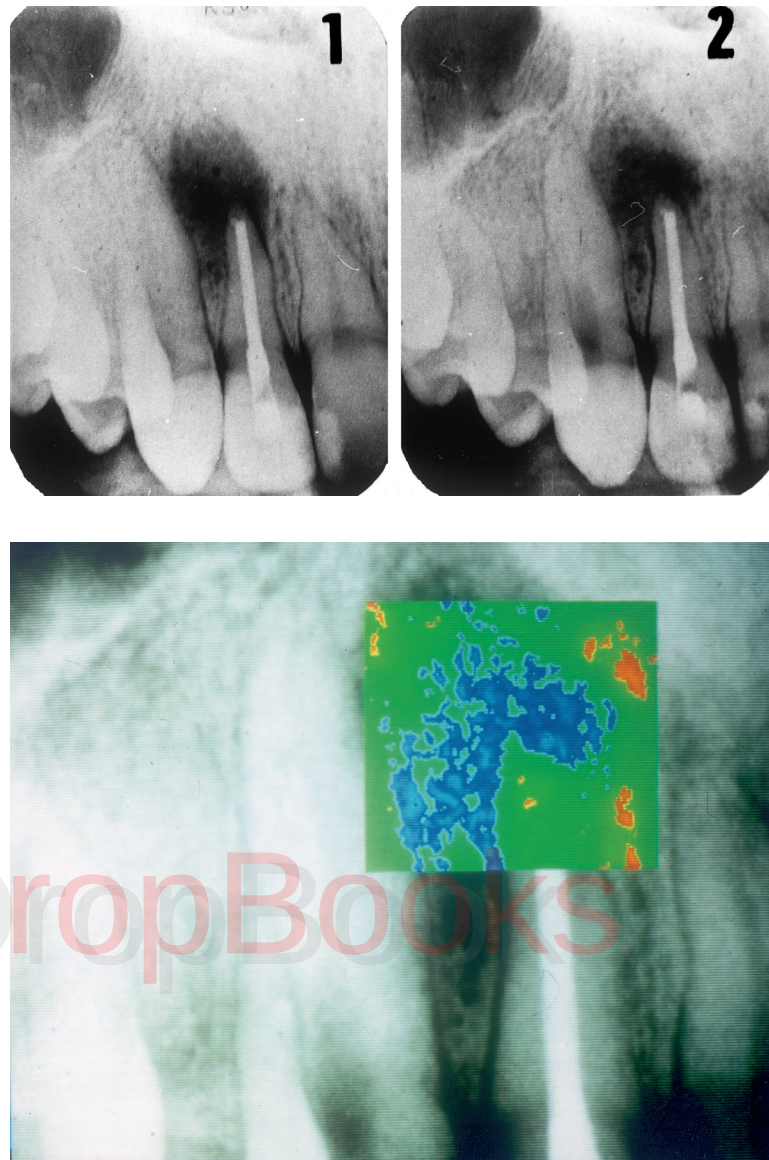


Figure 1 (a) Periapical radiograph immediately postoperatively and recall radiograph at 3 months. (b) Corresponding subtraction image. The colour-converted region of interest demonstrates the increase in density over 3 months projected on top of the radiograph obtained immediately postoperatively.

of the effect of root canal treatment on periapical lesions is only based upon the symptoms and radiographs. Since clinical symptoms occur infrequently, the incidence of pathologic alterations in the periapical tissue is largely determined by radiographic criteria. However, interpretation of radiographs may be an extremely subjective and inconsistent process despite the great effort that has been devoted to improving radiographic imaging systems. The rates of error in interpretation of radiographs remain alarmingly high. Clearly it is of great importance to be able to follow the radiographic changes within lesion.

The digital subtraction procedure provides a more quantitative and reproducible assessment of periapical lesions than conventional interpretation of radiographs. This study has shown that observer agreement in the evaluation of the effect of root canal treatment on periapical lesions is greater with digital subtraction radiography. In general, digital interpretation was significantly better than the conventional method for the detection of lesions. That means that the probability of detecting a lesion by digital pictures when a lesion is actually present is very high. Our results are in accordance with previous digital imaging studies, showing that the

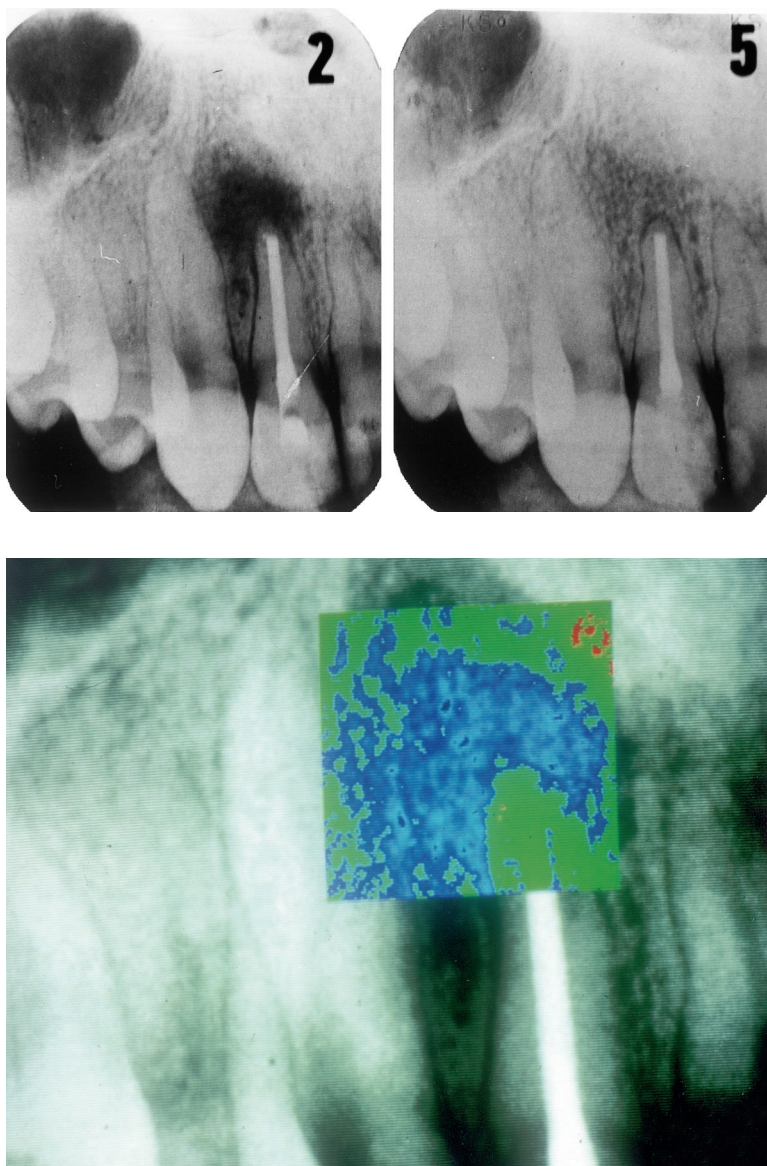


Figure 2 (a) Periapical radiograph at 3 months and recall radiograph at 12 months. (b) Corresponding subtraction image. The colour converted region of interest demonstrates the increase in density over 12 months projected on top of the radiograph obtained at the 3 months recall.

diagnosis of periapical lesions is improved considerably. Kullendorff *et al.* (1988) reported that subtraction radiography improves the detection of small lesions induced in dry human mandibles in the periapical area. They concluded that the results of their study indicated that the computer-assisted subtraction technique is a promising method to detect early periapical bone lesions of endodontic origin.

The area of diagnostic interest within a radiograph is that which changes over time. Pascon *et al.* (1987) demonstrated in an animal study that radiographic analysis by subtraction radiography showed hard tissue

changes as early as 77 days, and there was a correlation established between radiographic and histologic findings.

The interpretation of the results of the present report must consider that the effect of root canal treatment on periapical lesions was based upon conventional radiographs taken at the 1-year-recall when the changes (healing or not) were visible to the human eye. However, the true status of the periapical condition and of the apical seal are unknown and the actual condition might not be reflected by the 1-year radiographs. In a study by Halse *et al.* (1991) a total of 474 teeth treated with

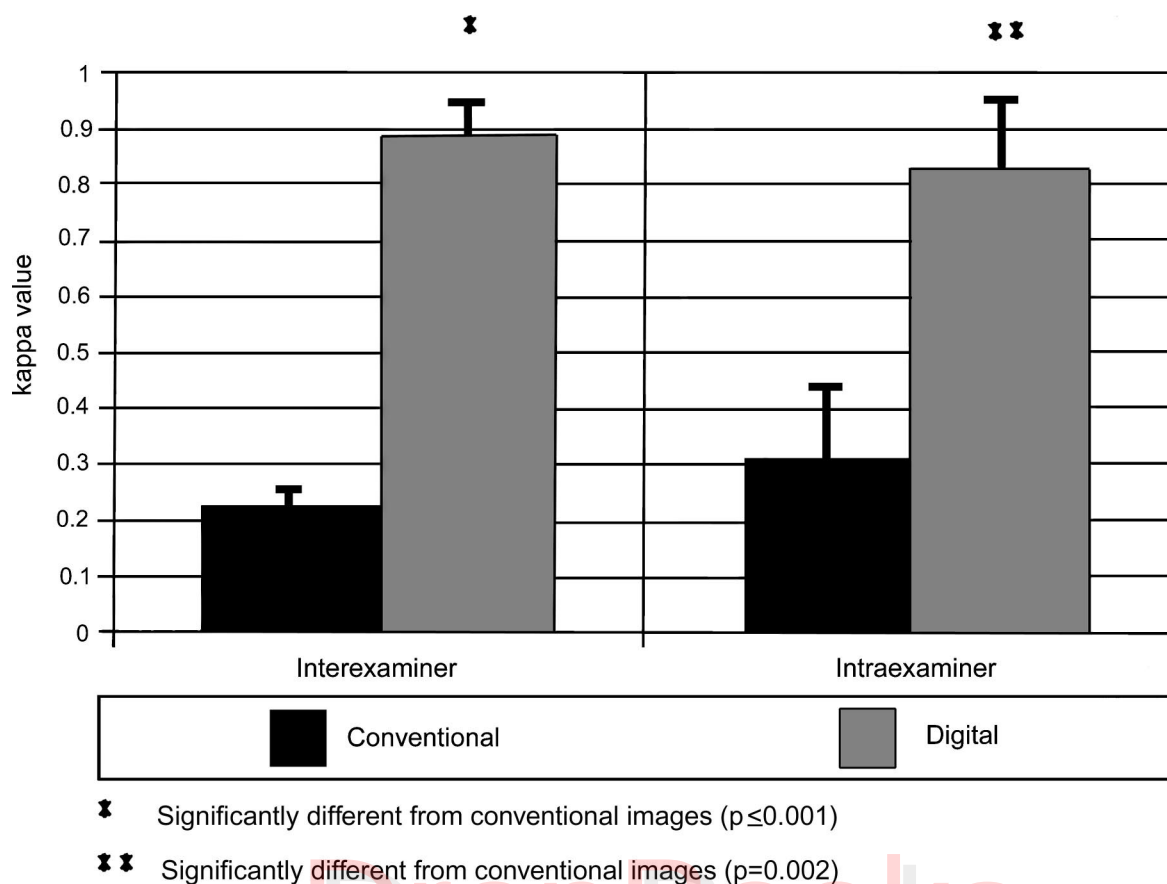


Figure 3 The inter- and intra-examiner agreement rates expressed as kappa values.

periapical surgery were examined after 1 year. They concluded that the 1-year control provided a valid diagnosis for the majority of cases.

Zakariassen *et al.* (1984) stated that any diagnostic test must exhibit both validity and reliability to be maximally useful. For correct diagnoses to occur, the diagnostic test must be reliable; i.e. multiple examiners must be able to arrive at the same diagnosis when presented with the same diagnostic data, and the same examiner must agree with himself/herself on repeated readings. Conventional radiographic methods for determining the presence, absence, extension or healing of a lesion in periapical bone are still relatively crude (Tidmarsh 1987). Technological developments such as digital subtraction radiography, however, significantly improve both the validity and reliability of such examination. The advantages of digital subtraction appear to lie in its ability to remove structured noise, thereby allowing detection of changes that the human eye cannot see on conventional radiographs. However, there are several disadvantages to digital subtraction that need to be

considered. The most critical component of a subtraction system is geometric reproducibility of the X-ray source-to-object relationship.

For many years, the contribution of radiography to the diagnosis of periapical bone lesions has been the subject of extensive research. Nowadays, the implementation of digital image analysis techniques in endodontics can result in greater diagnostic accuracy, because it enables the enhancement of specific features of interest to be carried out using objective methods. Lavelle & Wu (1995) stated that as digital radiographic images are potentially more versatile than conventional radiographs, digital images derived from conventional radiographs offer greater potential benefits for endodontic therapy and other aspects of dentistry than those obtained from intraoral sensors.

Clinically, this may mean that bone changes associated with pulpal pathosis may be detectable at a much earlier time. This may have potential treatment and/or prognosis implications. There are other clinical situations where digital subtraction may be useful in the

practice of endodontics. These include the monitoring of bone healing (because subtraction can detect bone additions subsequent to endodontic therapy), the evaluation of internal and external resorption and the evaluation of periapical scars present many years after clinically successful endodontic therapy.

Conclusions

It can be concluded that improving feature recognition led to better diagnostic accuracy of periapical bone lesions. Radiographic information can be used more effectively, whilst inter- and intra-examiner variability can be reduced. Clearly digital subtraction radiography observer agreement was highly significantly better during the evaluation of the effect of root canal treatment on periapical lesions.

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